WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
SJIF Impact Factor 8.453
Volume 14, Issue 17, 948-966. Research Article ISSN 2277–7105

FORMULATION AND CHARACTERIZATION OF HERBAL HAIR DYE

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Article Received on
10 July 2025,

Revised on 30 July 2025,
Accepted on 20 August 2025

DOI: 10.20959/wjpr202517-38098

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ABSTRACT

In recent years, there has been a growing interest in natural and chemical-free hair dyes due to worries about the adverse effects of synthetic alternatives. This research centers on creating and assessing a herbal hair dye utilizing plant-based components recognized for their hair coloring and conditioning abilities. The primary ingredients comprise Indigofera tinctoria (known as indigo), Lawsonia inermis (commonly known as Henna), Emblica officinalis (Amla), Hibiscus flower, and chamomile dried flowers each of which plays a role in enhancing hair color, nourishing hair, and promoting scalp health. The herbal powders were combined in specific ratios to produce a uniform herbal dye blend. Indigofera tinctoria serves as the main coloring component, with support from Henna, Hibiscus, Amla, and chamomile dried flowers. The dye was tested for its organoleptic, rheological, physicochemical, and stability characteristics. This study highlights the promise of herbal hair dye as a sustainable, eco-friendly, and non-toxic hair care solution. Further investigations are suggested to assess color retention, stability, and user satisfaction.

KEYWORDS: Indigofera tinctoria, Emblica officinalis, Henna, Hibiscus, Non-toxic, Eco-friendly.

INTRODUCTION

Nowadays, the majority of people take great care to maintain their appearance, and hair greatly contributes to this. For healthy hair, herbal medications that don't cause any side effects are used. A natural substitute for hair colouring products with chemical bases is herbal

hair dye. Herbal hair dyes, which are made from plant-based materials, are intended to colour hair with the least amount of harsh chemical exposure possible. The silver-colored hair was dyed a standard dark hue on the market using a variety of plant- based products, including henna, indigo, amla, bhringraj, black walnut hull, chamomile, and so on.

Various hair colours can be applied to the hair using a mixture of herbal dyes and hair colouring mordant. Colour saturation, colour development, accurate initial colour consistency, enhanced wash fastness, and better hair conditioning without causing skin irritation or hair damage, however, all require significant improvement. There is an urgent need for an alternative to the current black dye due to the manufacturing risks, environmental contamination, and its adverse and harmful impacts.

Only by substituting non-toxic substances made from herbal sources for the composition's parts can these limits of the chemically created colour be addressed. Black dye made from herbal materials can be applied to a wide range of products, including hair colour. A technique to boost the output of these colours from herbal items is of the utmost importance at this point.[1,2,3]

TIMELINE OF HERBAL HAIR DYE

A timeline of herbal hair dye was shown in the fig.no: 01

- **CIRCA 2177 BCE:** The earliest known Assyrian herbal texts feature recipes for cosmetic uses, including hair dyes made from natural substances, often derived from plants such as henna and indigo.
- **CIRCA 1550 BCE:** The Egyptian Ebers Papyrus includes formulas for coloring gray hair and eyebrows, where henna (Lawsonia inermis) was commonly used by ancient Egyptians as a natural hair dye for both aesthetic and symbolic reasons.
- **7TH CENTURY BCE:** Assyrian clay tablets reference the use of black ox gall, cypress oil, licorice, and honey for darkening gray hair, showcasing the application of natural ingredients in hair dyeing.

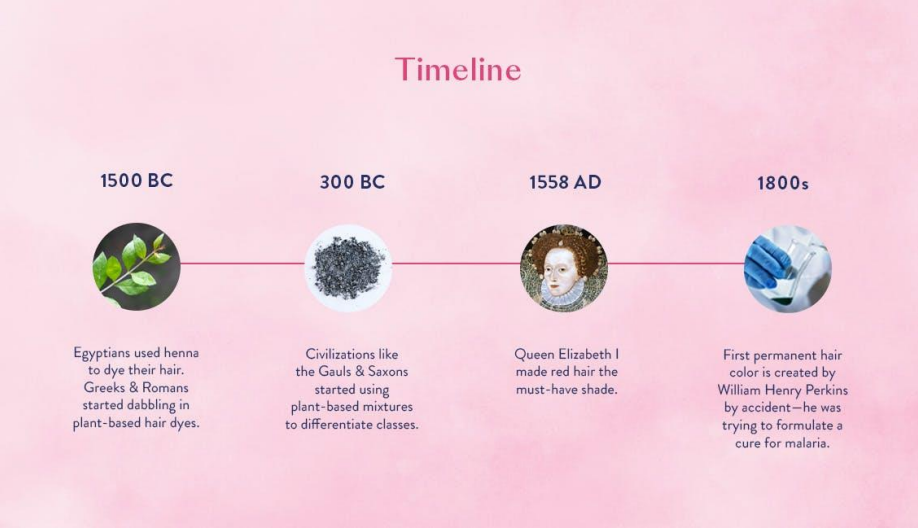


Fig. No: 01 Timeline of Herbal Hair Dye.

- **ANCIENT GREECE:** The Greeks created mixtures of natural components for hair dyeing, employing methods to bleach hair using potassium and using ointments made from flower petals and pollen, with a preference for black hair achieved through plant-based dyes.
- **ROMAN PERIOD:** The Romans utilized walnut extracts, ashes, and even gold dust as natural hair coloring agents.
- **MIDDLE AGES TO RENAISSANCE (from the 12th Century onwards):** Numerous recipes for bleaching and coloring hair with plants and natural materials were compiled in texts such as Trotula's De ornatu mulierum and other medieval manuscripts.
- **1500s:** Henna and indigo remained the main natural colorants, while the Spanish documented the use of logwood, and plant extracts like walnut and amla were prevalent for hair coloring.
- **19TH CENTURY:** The emergence of synthetic dyes began with William Henry Perkin's discovery in 1856, yet herbal dyes such as henna, indigo, and amla continued to be favored for their natural advantages and fewer side effects.
- **EARLY 20TH CENTURY:** The synthetic dye industry flourished, but herbal products still saw use for hair dyeing, providing temporary or semi-permanent results.
- **MODERN ERA:** There is a growing interest in herbal hair dyes due to their natural benefits and minimal adverse reactions. Scientific studies are concentrated on creating formulations using plant extracts like henna, amla, Bhringraj, and Tulsi for safer, natural hair coloring.[4,5,6,7,8]

CLASSIFICATION OF HERBAL HAIR DYE

1. Temporary Dye

- These types of hair colors are used for temporary dyeing.
- The colorants used do not penetrate the hair or surrounding areas.
- They can be easily washed out with one shampooing.
- Temporary hair color can sometimes be applied using finely ground metals with a Puffer Spray.
- Such metals, including brass, bronze, and aluminum, both untreated and anodized in various shades, provide a metallic effect when applied to hair, primarily used for highlighting.
- Powders, setting lotions, and crayons are among the materials used for temporary color.
- Temporary hair coloring can also be achieved using the leuco derivative of a basic dye, such as crystal violet.
- The different types of products available for temporary hair coloring include rinses, lotions, aerosols, and crayons.
- In rinses, simple dye substances are used in an aqueous or hydro-alcoholic solution.
- In lotions, dye is dissolved within a clear polymer, such as a 3% solution of polyvinyl pyrrolidone in water or aqueous alcohol.
- Crayons can be applied directly to wet hair by rubbing them on or using a hairbrush for application.

2. Semipermanent

- Most of these dyes are basic colorants, which have a cationic nature that allows them to bond naturally with hair.
- They contain metalized dyes combined with nitro derivatives of aromatic diamines or aminophenols.
- The effectiveness of colorants can be improved by adding a solvent.
- Shampoo is the base most commonly utilized for these dyes.
- Semipermanent dyes primarily consist of either nitrophenylene diamines nitroaminophenes, or aminoanthraquinones.

3. Permanent

- These are the most widely used hair dye products.
- The dyes are created during the dyeing process and are not present in the solution prior to

application.

- The formulation consists of two components:
  - Dye intermediate
  - Oxidizing agent

- Dye intermediates are combinations of primary intermediates along with a coupling agent or modifier within an appropriate base.
- When dyeing hair, the intermediate solutions are combined and then applied to the hair.
- The main intermediates are slowly oxidized and subsequently react with modifiers in a coupling reaction.
- Permanent dye formulations can lighten hair beyond its natural color.
- These dyes can mask the variation in color among individual strands of hair.
- They work particularly well on hair that is a mix of white and black shades.[9,10]

MERITS

- Herbal dyes are environmentally friendly and safe for consumers due to their natural origins.
- These dyes provide natural shades and contribute to a soft, calming appearance.
- The preparation of herbal dyes does not involve any chemical reactions.
- Herbal dyes pose no harm or health risks to users.
- There are no disposal issues associated with herbal dyes.
- Contains vitamins and antioxidants that nourish and strengthen hair.
- May help maintain natural hair pigment and slow premature greying.
- Can reduce dandruff, itching, and scalp inflammation.
- Does not have the pungent smell of ammonia-based dyes.
- Safe for frequent and long-term use.

DEMERITS

- It can be challenging to standardize or blend herbal hair dyes.
- Producing herbal hair dyes is difficult due to the limited availability of raw materials.
- The process of preparing herbal dyes can be time-consuming.
- Herbal dyes may not have a strong degree of fixation.
- The shade consistency of natural herbal dyes can be unreliable.
- Takes hours for colour to develop and some herbs have a strong earthy smell that some

dislike.

- ❖ Requires messy preparation and can stain skin or clothes.
- ❖ Results may vary depending on natural hair colour and herb quality.
- ❖ May not fully cover resistant grey hair in one application.

CHARACTERIZATION OF HERBAL HAIR DYE

The assessment of herbal hair dye includes a thorough investigation of its physicochemical, phytochemical, safety, and performance characteristics. This evaluation is especially crucial for formulations that incorporate traditional plant ingredients like henna (Lawsonia inermis), indigo (Indigofera tinctoria), amla (Phyllanthus emblica), hibiscus flower (Hibiscus rosa-sinensis), chamomile (Matricaria chamomilla), and lemon juice (Citrus limon), each adding distinct dyeing and conditioning attributes to the hair.

1. Organoleptic Assessment

The herbal blend undergoes visual and sensory examination concerning its color, texture, fragrance, and appearance. Henna provides a distinctive earthy aroma and a greenish- brown hue, while indigo delivers a deep blue shade. Amla and hibiscus introduce reddish tones, whereas chamomile yields golden-yellow colors. Lemon juice enhances the mixture with a refreshing citrus scent while acting as a natural pH balancer.

2. pH and Viscosity

The pH level of the dye mixture is vital for color development and compatibility with the scalp. Lemon juice aids in maintaining an acidic pH (approximately 4.5-5.5), which is optimal for hair health. Viscosity is modified for optimal application ease through the use of natural thickeners or powders like hibiscus and amla, and it is measured with a viscometer.

3. Phytochemical Analysis

Qualitative assessments validate the existence of important compounds:

- Henna – Lawsone (naphthoquinone)
- Indigo – Indigotin
- Amla - ascorbic acid and tannins while
- Hibiscus - anthocyanins and flavonoids
- Chamomile - apigenin and bisabolol,
- Lemon juice - citric acid and vitamin C.

These components contribute to dyeing, antioxidant capabilities, and scalp conditioning effects.

4. Dyeing efficiency and shade analysis

Hair samples are dyed and assessed with spectrophotometry or colorimetry using L*, a*, and b* values. The reddish-brown hue of henna arises from lawsone's bonding with keratin, and indigo interacts with hair that has been pre-dyed with henna to produce a deep brown or black shade. Amla and hibiscus improve the coloration, chamomile adds golden undertones, and lemon enhances the dye release from henna.

5. Microscopic and structural analysis

Scanning electron microscopy (SEM) is utilized to examine the surface alterations on hair strands, confirming dye adherence and the integrity of the cuticle. Fourier transform infrared spectroscopy (FTIR) is employed to detect the chemical bonds created between herbal agents and hair proteins.

6. Stability testing

Formulations are kept under varying temperature and humidity conditions. Important factors such as color intensity, pH, and viscosity are measured at intervals to evaluate stability. Generally, herbal dyes maintain stability for three to six months with appropriate storage.

7. Microbial and safety assessment

Herbal products are examined for microbial contamination, including total viable count, molds, and yeasts. Furthermore, patch testing and the Draize test for skin irritation are performed to ensure safety for human use. The presence of natural acidic ingredients such as lemon and antimicrobial plants like amla enhances the stability of preservatives.[11-17]

MATERIALS REQUIRED

Procurement of Raw Materials

The herbal powders of *Lawsonia inermis* (Henna), *Indigofera tinctoria* (Indigo), *Emblica officinalis* (Amla), *Hibiscus rosa-sinensis* (Hibiscus), and dried flower powder of *Matricaria chamomilla* (Chamomile) were procured from Herbal Care Shop, Tiruvannamalai, Tamil Nadu, India.

PREPARATION METHODS OF HERBAL HAIR DYE

1. Prepare chamomile decoction

Boil 5g dried Chamomile flowers in 100 ml of water for 10 minutes and filter it.

2. Prepare henna paste

Mix henna, amla, and hibiscus flower powder with chamomile decoction. Add lemon juice, cover, and rest for 6-8 hrs.

3. Prepare indigo paste

Mix indigo powder with warm water just before use.

4. Combine and apply

Mix indigo into henna paste. Apply to hair for 2-4 hours. Rinse without shampoo. The materials used in the Herbal Hair dye was summarized in the Table No. 01.[18,19,20]

Table No. 01: Ingredients used in the Herbal hair dye.

S. No	Common Name and Botanical Name	Picture	Quantity	Role of Activity
01	Henna powder (lawsonia inermis)		35g	Natural dye, strengthens hair shaft, adds shine
02	Indigo powder (Indigofera tinctoria)		25g	Used in combination with henna to achieve darker shades
03	Amla powder (Emblica officinalis)		**10g**	Promotes hair growth, prevent premature graying and dandruff
04	Hibiscus flower powder (Hibiscus rosa-sinensis)		**5g**	Natural conditioner
05	Charmomile dried flowers (Matricaria recutita)		**5g**	Lighten hair colour, soothing properties
06	Lemon juice (Citrus limon)		**5-10 ml**	Natural bleaching agent(PH adjuster)

EVALUATION METHODS OF HERBAL HAIR DYE

A variety of parameters, including organoleptic, physico-chemical, phytoconstituent, and micromeritic aspects, were assessed for the manufactured herbal hair colour.

ORGANOLEPTIC EVALUATION

Organoleptic characteristics for a variety of sensory characteristics, such as colour, odor, taste, etc., were carefully determined.

PHYSIO-CHEMICAL EVALUATION

The physical and chemical characteristics of the herbal hair dye were assessed in order to calculate its pH, moisture content, solubility, and washability.

pH

A 1g sample of the powder was dissolved in distilled water, and the pH of the resulting solution was measured using a pH meter.

Washability

The formulation was applied to the skin, subsequently rinsed with water, and then evaluated manually for its effects.

Solubility

Solubility is defined as the ability of a solute to dissolve in a given solvent. 1g of powder was accurately weighed and mixed with 100ml of water in a beaker. The mixture was agitated, warmed, cooled, filtered, and the leftover residue was weighed and recorded.

Moisture content

Moisture content was determined using the Loss on Drying (LOD) method, where the crude drug was heated at a constant temperature, and the weight loss was calculated to determine the moisture content.

PHYTO-CONSITUENTS EVALUATION

To find out whether herbal formulations include bioactive chemicals, phytochemical screening is crucial. Henna, Amla, Indigo, Hibiscus flower, Chamomile, Lemon juice, and warm colour extracts make up the natural hair colour mixture under investigation. The qualitative phytochemical tests that were performed for these components.

MICROMERITIC EVALUATION

Bulk density

5g of dye powder were precisely weighed and moved to 100 ml measuring cylinder in order to calculate the bulk density. The initial volume was noted after the powder was gently levelled without being compressed.

Formula: Mass / Bulk Volume

Tapped density

To measure the tapped density, 5g of dye powder was precisely weighed and transferred to a 100ml Measuring cylinder. The cylinder was then tapped for 1minute to settle the powder, and the resulting volume was carefully recorded. The tapped density was subsequently calculated using the given formula.

Formula: Mass/ Tapped volume

Angle of repose

To evaluate powder flow capabilities, the angle of repose was measured using a funnel method. The resulting value was then computed using the given formula:

Formula: $\tan \theta = h/r$

Where,

θ = Angle of repose

h= height of pile of the powder

r = radius of pile of the powder

Carr's index

It measures the compressibility of a powder, which is an indirect indicator of its flow properties.

Formula: Tapped density – Bulk density / Tapped density * 100

Hausner' ratio

It is the ratio of tapped density to bulk density of a powder, indicating how much the powder volume reduces upon tapping.[21,22,23,24,25]

Formula: Tapped density/ bulk density

PATCH TEST

This typically involves applying a small amount of diluted hair dye solution behind the ear or

on the inner elbow in a 1 sq.cm area and allowing it to dry. Any signs of irritation or feelings of discomfort are observed, if present. Carefully measured and small amounts of the prepared hair dye mixture were applied to the designated area for a specific duration. Symptoms of irritation, including redness and swelling, were monitored and recorded at regular intervals for up to 24 hours.

STABILITY TESTING

Stability testing for the formulated product was conducted by keeping it at various temperature conditions over a one-month period. The sealed glass vials containing the formulation were stored under different temperature conditions to assess physical attributes such as color, odor, pH, texture, and smoothness were determined.

RESULTS AND DISCUSSION

The Herbal hair dye was prepared and evaluated for the Organoleptic evaluation, physicochemical evaluation, Phytoconstituents evaluation, and Micromeritic evaluation.

ORGANOLEPTIC EVALUATION

As shown in Table No. 2, organoleptic characteristics for a variety of sensory characteristics, such as colour, odor, taste, etc., were carefully documented. The raw medications and powders were examined individually by organoleptic and morphological characteristics, such as colour, odor, texture, and appearance.

Table No. 02: Organoleptic characters of Herbal Hair Dyel.

S.NO	PARAMETERS	RESULTS
01	Colour	Greenish black
02	Odour	Characteristics
03	Texture	Fine
04	Appearance	Powder

PHYSIO-CHEMICAL EVALUATION

For stability, compatibility, and the amount of inorganic matter present, the physical and chemical characteristics of the herbal hair dye were assessed in order to calculate its pH, moisture content, solubility, washability. The results above are shown in Table No. 3.

Table No. 03: Physicochemical characters of Herbal Hair Dye.

S.NO	PARAMETERS	RESULTS
01	PH	6.6
02	Washability	Easy washable
03	Solubility	Soluble in water
04	LOD	9.6%

PHYTOCONSITUENTS EVALUATION

To find out whether herbal formulations include bioactive chemicals, phytochemical screening is crucial. Henna, Amla, Indigo, Hibiscus flower, Chamomile, Lemon juice, and warm colour extracts make up the natural hair colour mixture under investigation. The qualitative phytochemical tests that were performed for these components are summarized in Table No. 04 below.

Table No. 04: Phytoconstituents Evaluation Of Herbal Hair Dye.

S. No	Phytochemical Test	Procedure	Observation	Inference
1	Test for Alkaloids (Mayer's, Wagner's reagent)	Mix 2 mL extract with 2 drops of Mayer's or Wagner's reagent.	Creamy white (Mayer's) or reddish-brown (Wagner's) precipitate	Presence of alkaloids (in Indigo, Chamomile)
2	Test for Tannins (Ferric chloride test)	Add 3 drops of 5% $FeCl_3$ to 2 mL extract.	Blue-black or greenish-black color	Tannins present (in Amla, Henna)
3	Test for Flavonoids (Alkaline reagent test)	Add 2 mL NaOH to extract and shake.	Yellow color that disappears on adding dilute acid	Flavonoids present (in Chamomile, Hibiscus)
4	Test for Saponins (Foam test)	Shake 2 mL extract with 5 mL water.	Persistent foam for 10 mins	Saponins present (in Hibiscus, Amla)
5	Test for Glycosides (Keller-Killiani test)	Add 2 mL glacial acetic acid, 1 drop $FeCl_3$, and 1 mL H_2SO_4.	Reddish-brown ring between layers	Cardiac glycosides present (in Chamomile)
6	Test for Anthocyanins	Add dilute HCl and observe red; add alkali and observe blue/green.	Color change red ↔ blue	Anthocyanins present (in Hibiscus flower)
7	Test for Phenolic Compounds (Ferric chloride)	Add 3 drops of $FeCl_3$ to extract.	Blue or green coloration	Phenols present (in Amla, Henna)
8	Test for Terpenoids (Salkowski test)	Mix extract with chloroform and H_2SO_4.	Reddish-brown interface	Terpenoids present (in Lemon juice, Chamomile)
9	Test for Citric Acid (Calcium carbonate test)	Add $CaCO_3$ to lemon juice extract.	Effervescence due to CO_2 release	Citric acid present (in Lemon juice)

10	Test for Coumarins (UV test)	Add NaOH, shake, expose to UV light.	Blue fluorescence	Coumarins present (in Chamomile)

Micromeritic evaluation

The prepared herbal hair dye was evaluated for micromeritic properties such as Bulk density, tapped density, Angle of repose, Carr's index, and Hausner's ratio. The results of the micromeritic evaluation were tabulated in Table No. 05. The powder shows good flow property

Table No. 05: Micromeritic Evaluation for Herbal Hair Dye.

S.NO	PARAMETERS	RESULTS
01	Angle of repose	35.30
02	Bulk density	0.55 gm/ml
03	Tapped density	0.78 gm/ml
04	Carr's index	30.3%
05	Hausner's ratio	1.25
06	Flow rate	0.51 gm/sec

PATCH TEST

This typically involves applying a small amount of diluted hair dye solution behind the ear or on the inner elbow in a 1 sq.cm area and allowing it to dry. Any signs of irritation or feelings of discomfort are observed, if present. Carefully measured and small amounts of the prepared hair dye mixture were applied to the designated area for a specific duration. Symptoms of irritation, including redness and swelling, were monitored and recorded at regular intervals for up to 24 hours. The outcomes of the irritation tests are presented in Table No. 06.

Table No. 06: Patch Test Results Of Herbal Hair Dye.

S.NO	PARAMETERS	RESULTS
01	Swelling	Negative
02	Redness	Negative
03	Irritation	Negative

STABILITY TESTING

Stability testing for the formulated product was conducted by keeping it at various temperature conditions over a one-month period. The sealed glass vials containing the formulation were stored under different temperature conditions to assess physical attributes such as color, odor, pH, texture, and smoothness, as shown in Table No. 07.

Table No. 07: Stability Test Results of Herbal Hair Dye.

S.No	Parameters	Room temperature	35°C
01	Colour	No change	No change
02	Odour	No change	No change
03	PH	6.6	6.8
04	Texture	Fine	Fine
05	Smoothness	Smooth	Smooth

CONCLUSION

All of the benefits of natural substances are present in the herbal hair dye. The herbal hair dye serves as a conditioner, anti-dandruff agent, hair nutrient, and hair growth stimulant. Herbal hair dye's natural elements prevent greying, limit hair loss, give hair gloss, and fortify it. Herbal hair dye's antioxidants must cleanse the scalp, eradicate microorganisms that cause infections, and promote hair growth. Because it contains natural ingredients, consistent usage of herbal hair dye results in smooth hair and a great impact. Because of its non-toxic, non-habit-forming, and chemical-free qualities, it also helps to extend the shelf life of herbal hair dye. We discovered in this study that the herbal hair pack has helpful qualities, but more research is required to learn more about its potential uses.

FUTURE ASPECTS OF HERBAL HAIR DYE

Innovation in the herbal hair dye industry is booming as it responds to consumer demands for multipurpose, sustainable, and safer substitutes for chemical dyes. The following patterns point to potential paths for the future:

1. **Improved Colour Performance:** By refining plant pigment extraction and mordanting techniques, research is being conducted to intensify colour shades, prolong colour retention, and broaden the dye palette.
2. **User-Friendly Formulations:** To appeal to modern-day users, product development attempts to enhance application simplicity and decrease processing time.
3. **DIY Trends and Customization:** As interest in customized beauty grows, DIY kits are becoming more popular, enabling users to create natural hues with hibiscus, amla, and henna.
4. **Sustainable and ethical approaches:** Ethical sourcing, environmentally friendly packaging, and biodegradable formulations are emerging as key tactics for producers who care about the environment.
5. **Advantages for Hair and Scalp Health:** Added therapeutic advantages from herbal substances, such as antibacterial, anti-inflammatory, and conditioning qualities, improve

the general health of the scalp.

6. **Technological Developments:** Methods like Nano encapsulation are being investigated to increase colour penetration, regulate release, and stabilize dyes.
7. **Growing Awareness and Market Expansion:** Influencer marketing, social media, and natural beauty movements are all contributing to consumer understanding and the widespread use of herbal hair dyes worldwide.

APPLICATIONS OF HERBAL HAIR DYE

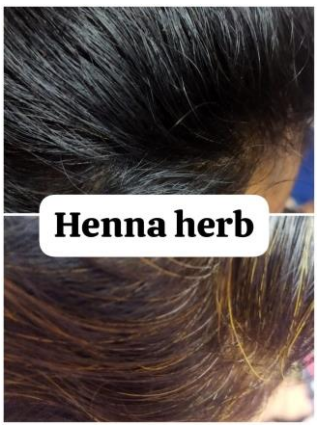
1. **Herbal coloring agents:** such as henna, indigo, jatamansi, hibiscus, and bhringraj offer natural color to hair, producing hues from reddish-orange (due to lawsone in henna) to deep black shades (achieved through a mix of indigo, jatamansi, and other herbs), free from the toxic chemicals present in artificial dyes.

2. **Prevention of Early Greying:** Some herbal mixtures have been discovered to help prevent or postpone the onset of premature greying of hair, which is due to their antioxidant and nourishing qualities, including those that feature amla and bhringraj.

3. **Anti-dandruff and scalp health:** Herbal hair dye formulations are effective in treating dandruff and enhancing scalp health due to the antimicrobial and anti-inflammatory properties of ingredients like hibiscus, bhringraj, and jatamansi.

4. **Conditioning and shining:** Herbal dyes help achieve softer, silkier hair while boosting natural shine and minimizing damage caused by chemical treatments.

5. **Safe and reduced toxicity:** These natural hair dyes do not contain harmful chemicals such as ammonia, parabens, and PPD (p-phenylenediamine), reducing the chances of allergic reactions and long-term health concerns linked to synthetic dyes.



6. **Synergistic effects of combination:** Using a combination of herbs in specific proportions can lead to improved coloring, conditioning, and protective effects; for instance, blending henna with indigo and jatamansi results in a darker, longer-lasting hair color along with added hair care benefits.

7. **Encouraging Hair Growth:** Various herbs found in herbal hair dyes, such as amla, bhringraj, shikakai, and reetha, provide nourishment to the scalp and bolster hair follicles, which in turn fosters hair growth and minimizes hair loss.

Research has demonstrated the successful use of herbal hair dyes on a variety of hair shades, including blonde, highlighting their versatile applicability across different hair types and colors, although further studies are needed to explore a broader range of variations.[24,25]

ACKNOWLEDGEMENT

We express our sincere gratitude to the management of Kamalakshi Pandurangan College of Pharmacy, particularly Dr. D. Rajalingam, Principal, Dr. N. Gnanasekar, Vice Principal, Dr. V. Kannabirran, Professor cum Head, Mr. K. Senthil Kumar, Associate Professor, Vasanthi Kalidass, Assistant Professor, Department of Pharmaceutics, faculties, and non-teaching staff for their invaluable guidance, support, and assistance in the successful completion of our project.

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